Derivation of the 3D Structure of Flares in the Homologous Flare Series of 1992 February

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Abstract

In February 1992, three flares, which we consider constitute a homologous flare series, occurred in the active region NOAA7070, and were observed by the Yohkoh SXT. In this paper, we discuss the 3D structure of arcade type flare by making use of the different perspectives of the flare in the homologous flare series.

Key words: Sun: arcade flares — Sun: homologous flares — Sun: X-rays — Sun: magnetic fields

1. Introduction

In order to understand the mechanism of arcade type flares, it is important to determine its 3D magnetic structure. On 21 February 1992, a flare which had a beautiful "cusp" occurred at the East limb of the Sun. The cusp of this flare is considered to be caused by magnetic reconnection at an X-point, and is taken to be evidence that this arcade type flare occurred with magnetic reconnection (T. Tsuneta et al. 1992). In the present paper, we note that two flares — 24 February 1992 and 27 Feburuary 1992 — which look homologous to each other occurred in the same active region. If those two events are actually homologous, we can examine whether the first one, the Feb 21 flare, might also be homologous to the latter two. In case we could identify those as a series of homologous flares, we can discuss their 3D structure by comparing the corresponding features seen from different angles. We use a relative time scale normalized by the duration of each flare and define phases to compare the corresponding features in the series. We also used the Kitt Peak Magnetograms and Mitaka Hα images for comparative analysis.

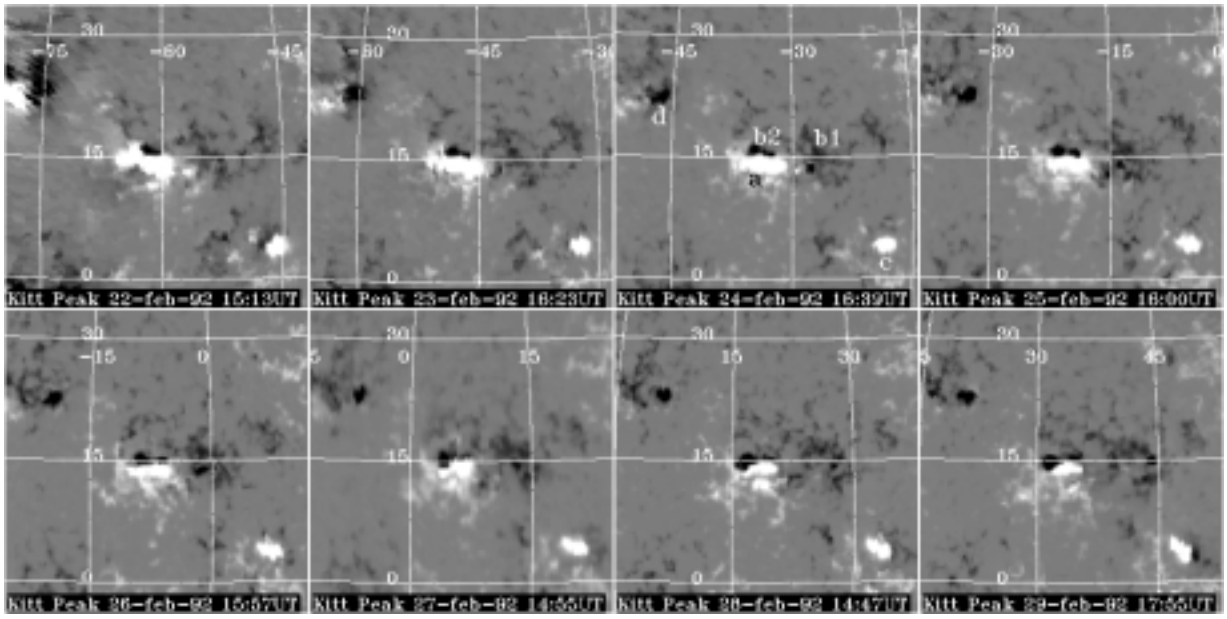

Fig. 1.. Kitt Peak Magnetograms of 8 days.

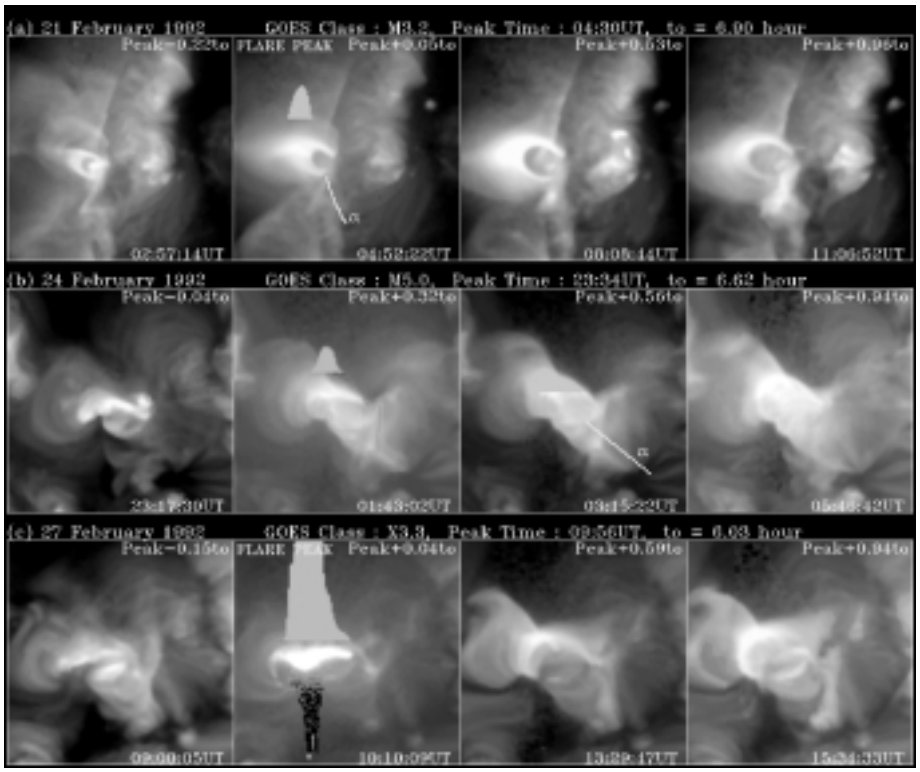

Fig. 2.. Time development of the three flares, which we consider to be a homologous flare series.

2. Examination of the Homology

We can demonstrate from the following comparison of the magnetic field distribution in the photosphere, that this flare series actually constitutes a homologous series (cf. Fig. 2.). Fig. 1. shows the 8 days evolution of the photospheric magnetic sources, corresponding to the series of flares, from 22-Feb to 29-Feb-1992 in the Kitt Peak Magnetograms. Because of the 21-Feb flare is the limb flare, we used the 22-Feb magnetogram for this one. In this figure, images have been rotated to show the top view of active region NOAA7070 in each panel for the sake of comparison. The pair of magnetic sources at the center of each image — named **a** and **b2** in this figure — is NOAA7070. We also see other two magnetic sources on both sides of the main active region. Those are NOAA7068 — plus polarity source named **c** in this figure — and NOAA7074 — minus polarity source named **d** — respectively. From the comparison between soft X-ray images and magnetograms, these outer two active regions(**c** and **d**) also relate the soft X-ray structures of flares, although the main structure of each flare is on the main active region(**a** and **b2**) and the week and wide-spread magnetic source(**b1**) (cf. Fig. 3.). Examining these 8 days images for the series of events, we found that there are no systematic remarkable changes, like a systematic long-distance shearing motion, with respect to these five magnetic sources, although there are many small scale changes near these five sources. We consider that this provides the basis for the homology.

3. Three dimensional structure

Fig. 2. shows the time development of the three flares in Yohkoh SXT. In this figure, the top, middle and the bottom panels of images are of the 21-February, 24-February and 27-February-1992 flares, respectively. Here, the four consecutive panels are at the corresponding stages in the scaled-times. These four stages are, from the left to the right, the pre-flare stage, flare-peak stage and two post-flare stages, respectively. Here, the flare-peak image of 24-February is not the image of the peak-time in the strict sense, because of the satellite night. It is an image nearest to the time of the peak, and actually somewhat after the flare-peak. Comparing these images, we see that

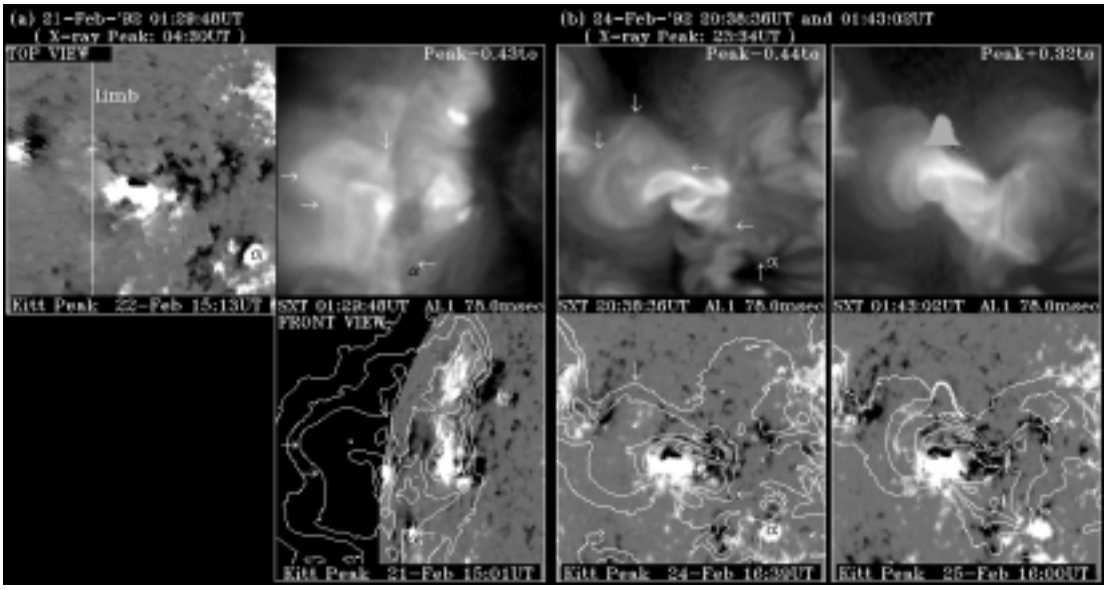

Fig. 3.. Comparison between the limb event 21-Feb.-1992 and disk event 24-Feb.-1992 flare with the SXT images and Kitt Peak magnetograms.

there exists a homology also in X-rays in this flare series. We could see that the shapes of each stage of flares and development of these are fairly similar. If so, we have information of a structure seen from different perspectives, and thus, we can discuss the 3D structures of these arcade flares from the comparative study of these pictures at each stage (cf. Fig. 2. and Fig. 3.). From these analyses, we obtained many new and remarkable findings. These are as follows:

1. The line of sight to flare cusp of 21-Feb-1992 has been considered to be along the axis of the flare arcade, but it is seen in this analysis to make about 30 degrees from the direction of the axis of the flare arcade that is produced in the later phase (See the line named α in Fig. 2.). Furthermore, in the early stage of the flare-peak, the cusp turned out to be a single arch structure with a thin blade type structure at its high side, over one of the "diagonal line" of the flare arcade that appears at later stage.

2. The narrow S-shaped structure, which existed in soft X-rays in the pre-event phase of the disk events, corresponds to the bright arch structure in the pre-event at the 21-Feb-1992 limb event. This structure is a common structure, and is quite a fundamental structure. Furthermore, this pre-event S-type structure developed into that thin blade type bright structure over one of the "diagonal line" of the flare arcade in the early stage of the flare-peak.

3. In the flare event on 24-Feb-1992, the configuration of the soft X-ray arcade changes in time, but its diagonal line keeps its location with respect to the S-shaped X-ray structure, which already existed in the pre-event phase. We can also see the same thing in the Hα images, observed at Mitaka, which show the footpoints of the arcade, more clearly. Furthermore, examination of the footpoints of the flare arcades shows that the footpoints do not correspond to any conspicuous magnetic features, while we can see the soft X-ray flare arcades in the decay-phase in the disk events of 24-February and 27-February-1992.

4. Four or more magnetic sources participate in the coronal structures that are brightened in the flare. In addition, from another image, in the pre-event phase of 21-Feb-1992, we can see that there exist high altitude faint loops connecting back to the photosphere on both sides. These connections turned out to be the connections **a** to **d** and **b1** to **c** in Fig. 1. The X-ray blob was observed to be pulled out by the started expansion of them (Morita et al. 1999). It is not that the rising blob pulled the convex loops and eventually cut them open, but the blob is being pulled by the rising loops out of the sharp valley right at the top of the cusp.

Considering the above new and remarkable findings carefully, we arrived at the following simple interpretations, by discussing the three dimensional structures of these arcade type flares. For example, this flare series have a "cusp",

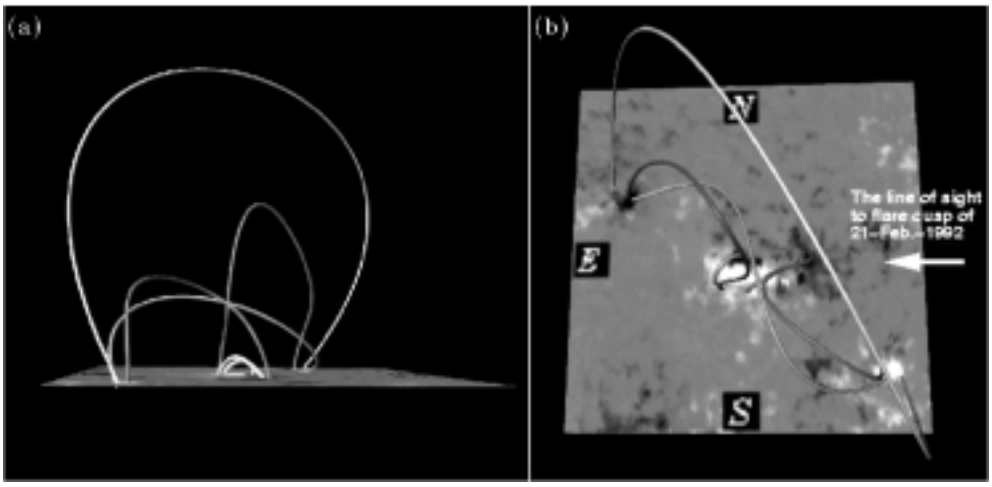

Fig. 4.. 3D schematic pictures of an empirical model deduced from observation. (a) The line of sight view of this model. It corresponds to the line of sight to flare cusp of 21-Feb.-1992. (b) The top view of this model. (24-Feb.-1992)

and this means that the magnetic X-point is located above the cusp. In addition, according to the above findings (ii), this "cusp" corresponds to the narrow S-shaped X-ray structure, and so it means that the magnetic X-point is located above the S-shaped structure in the pre-event phase from the top view of this configuration. Furthermore, in this flare series, there aren't any particular photospheric magnetic features that correspond to the above flare arcades, and this means that the magnetic field lines extending from such ordinary locations have been taken into the magnetic neutral sheet in the critical field structure at which the reconnection occurs in a systematic way. As a result of the above considerations of the features seen from different view angles in soft X-ray images, we deduced one empirical model that can explain the above findings remarkably well. Fig. 4. gives the 3D schematic pictures of an empirical model deduced from observation. These two pictures show different line-of-sight views of this model, with only the main magnetic flux tubes bright at the pre-flare stage. The left picture is the line-of-sight view of this model which corresponds to the observed line of sight to the flare cusp of 21-February-1992, and the right picture is the top view of this model, which corresponds to the 24-February and 27-February flare. In this figure, we can see the X-point between the two flux tubes. The involved lines correspond to the connections **a** to **d** and **b1** to **c** in Fig. 1. (cf. (iv)). After the reconnection, the lower part of these two flux tubes becomes the flare "cusp" (cf. (i) and (ii)), and the upper part of these becomes one bound loop and will expand (cf. (iv)). Another lower altitude flux tube, which corresponds to the connections **c** to **d** in Fig. 1, is a special structure, which passes through the X-point above (cf. (iii)).

4. Discussion and Conclusion.

In the previous section, we deduced a 3D empirical model from observations. In addition, in section 2, we also found that the configuration is involved with five magnetic sources in the photosphere, whose relative configuration has no remarkable systematic change over the 8 days of this flare series. We calculated a potential field above the photospheric source configuration of the main five magnetic sources, and then, we could see structures very similar to our empirical model. We could also see the arcade type structure around the above structures of this model in the calculated potential field.

In summary, the flare series of February-1992 can be considered to constitute a homologous series in a rough sense. Thus, from the corresponding features seen from different angles in SXT images, we deduced one 3D empirical model of this arcade type flare that can explain the new findings remarkably well. In addition, the configuration of this empirical model seems to correspond to a possible configuration of the separatrix surface for the potential field having those sources in the photosphere.

References

V. Gaizauskas, Z. Švestka 1987, Sol. Phys. 114, 389
Tsuneta, S., Hara, H., Shimizu, T., L. W. Acton, K. T. Strong, H. S. Hudson, Ogawara Y. 1992, PASJ, 44, L63
Uchida, Y. 1980, in Solar Flares, ed. P. Sturrock (U. Colorado Press), pp.67, 110
Uchida, Y., Hirose, S., Morita, S., et al., 1999, Astrophys. Space Sci., in press.